FIRST DRAFT REPORT

For

NCHRP PROJECT 20-5

TOPIC 36-02

PRACTICES FOR MONITORING SCOUR CRITICAL BRIDGES

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TRB

Transportation Research Board

Synthesis Studies

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SUMMARY

In the Untied States over 60 percent of bridge failures occur due to scour. The number of bridges declared "scour critical" total over 26,400. Following the successful completion of NCHRP Project 21-03 *Instrumentation for Measuring Scour at Bridge Piers and Abutments* (1), approximately 100 of these bridges have been instrumented for scour measurements. Scour monitoring is an efficient, cost-effective countermeasure alternative. Often these bridges are instrumented because the scour estimates seem overly conservative and it is prudent to observe scour activity during flood events before spending resources on other types of countermeasures. Other bridges are scheduled to be replaced, and monitoring is a cost-effective alternative to ensure the safety of the traveling public until the new bridge is completed.

This synthesis is a report of the state of knowledge and practice for fixed scour monitoring of scour critical bridges. The use of scour monitoring technology in the Untied States has led to the development of several fixed instruments suitable for different types of sites and structures. It includes a review of the literature and research, and an examination of current practice. The project included a survey of transportation agencies and other bridge owners to obtain their experience with fixed scour monitoring systems. In-depth, follow-up interviews were conducted with several states. For those agencies that have not employed scour monitoring systems, their opinions regarding problems and recommended improvements or advancements were asked.

Many of these instrumented bridges have been monitored for more than eight years and some very valuable field data may have been accumulated. Exploring what data and associated evaluations are available will be very useful for improving the technologies of predicting bridge scour as well as monitoring scour.

Approximately 25 of the 50 states use, or have employed fixed scour monitoring instrumentation on their highway bridges. A total of 93 bridge sites were identified that use fixed monitors. The respondents to the survey provided information on their experience with fixed scour monitoring installations, and detailed data on at least one representative bridge site. Not surprisingly, the states that had the largest number of scour monitoring installations were also locations with extreme weather conditions, Alaska and California. The systems used by all the states are those described in the current FHWA guidelines on scour monitoring (3). The problems reported by the states were very similar. The difficulties with maintenance and repairs to the scour monitoring systems were the most common theme throughout the survey responses. The leading cause of damage to the systems was debris flows and accumulation. Other common problems were vandalism and corrosion.

The advancements that bridge owners would like to see for future fixed scour monitoring technology included the development of durable instrumentation, with increased reliability and longevity, decreased costs, and minimum or no maintenance. This equipment would include instrumentation that measures scour, water elevations, and velocities.

CHAPTER ONE

INTRODUCTION

PROBLEM STATEMENT AND SYNTHESIS OBJECTIVES

This synthesis is a report of the state of knowledge and practice for fixed scour monitoring of scour critical bridges. It includes a review of the literature and research, and an examination of current practice. The project included a survey of transportation agencies and other bridge owners to obtain their experience with fixed scour monitoring systems. For those agencies that have not employed these systems, their opinions regarding problems with these systems and what they would like to see for systems were asked.

There are over 26,400 scour critical bridges in the United States, some of which are monitored by fixed instrumentation. Following the successful completion of NCHRP Project 21-03 *Instrumentation for Measuring Scour at Bridge Piers and Abutments* (1), approximately 100 of these bridges have been instrumented for scour measurements. Often these bridges are instrumented because the scour estimates seem overly conservative and it is prudent to observe scour activity during flood events before spending resources on other types of countermeasures. Other bridges are scheduled to be replaced, and monitoring is a cost-effective alternative to ensure the safety of the traveling public until the new bridge is in place.

Many of these instrumented bridges have been monitored for more than seven years and some very valuable field data may have been accumulated. Exploring what data and associated evaluations are available will be very useful for improving the technologies of predicting bridge scour as well as monitoring scour. The focus of this study is on fixed instrumentation.

Information gathered and synthesized included, but was not limited to:

- Fixed scour monitoring instruments currently being used.
- Experience with these fixed instruments including
    - Reliability of scour monitoring installations,
    - Advancements since the completion of the NCHRP project, including innovations to the recommended instrumentation;
    - Recommended improvements to equipment used at future sites
    - Evaluation of benefits of instrumentation.
    - Costs, including purchase, installation, and maintenance
    - Longevity and reliability of individual devices
    - Office responsible for scour monitoring
    - How has the information obtained from monitoring been useful for changes in bridge scour rating (item 113), plan of action, or verify scour predictions?
- Identify bridges that have been or are being monitoring with fixed instrumentation,
- Fixed instrumented data being collected / preserved, such as velocity, water depth, and scour

depth. This includes a detailed description of this data, and some illustrative samples.

- For sites where scour depth has been observed and preserved, data on site specific conditions for sites associated with instrumented bridges, such as bridge and channel geometry, soil conditions, etc.
- Based on other existing databases, suggestions on how a national database might be structured, and what elements it might contain.
- Potential sites for future in-depth monitoring case studies
- Future research needs associated with fixed monitoring, such as-
    - Measured vs. computed pier scour depths for different soil types, riverine and tidal environments, and complex pier scour
    - Assembling and maintaining a national scour database, and what items might be in the database
    - Incentives for owners to keep, rather than discard data collected
    - Bridges with tidal influences

The synthesis will serve as the foundation for a national database and a valuable resource to engineers and researchers for assessing the accuracy of various scour estimating procedures currently in use. In addition, the synthesis may serve to document the success or failure of the various scour monitors that have been deployed, and to obtain ideas as to what can be done to improve the reliability of existing monitoring equipment.

LITERATURE AND DATA SOURCES

The sources of information used for developing the synthesis included a literature search, a survey to bridge owners in the United States, and interviews with owners and others with experience in fixed scour monitoring instrumentation for bridges. The literature search and sources, included databases that include TRIS, the USGS National Bridge Scour, Abutment Scour (SC), NIS, and others. A detailed survey of the evolution of scour measuring instrumentation was presented at the TRB Third Bridge Engineering Conference in 1991 (2). The final report for NCHRP Project 21-03 (1) includes an extensive bibliography on instrumentation for measuring and monitoring scour. The most recent FHWA guidelines on scour monitoring instrumentation may be found in Hydraulic Engineering Circular 23 (HEC-23), *Bridge Scour and Stream Instability Countermeasures – Experience, Selection, and Design Guidance* (3). This was published in 2001 and also includes a list of references. The documents listed in the Reference section in this report include some of the key references for fixed scour monitoring instrumentation, new references that have been published since the publication of the FHWA HEC-23 guidelines, and some additional references that provide more detailed information on scour monitoring installations that were used in the development of this report.

A survey on the use of fixed scour monitors was prepared and distributed to bridge owners. The survey may be found in Appendix A. This survey was distributed by TRB to the 50 state DOTs, and to Puerto Rico. The surveys were e-mailed to the DOT State Bridge Engineer, and they were asked to forward copies to those departments in their agency with experience in scour monitoring instrumentation. A list of the respondents to the survey and the department within each agency that completed the survey, may be found in Appendix G. A summary of responses to the surveys may be found in Appendix B.

REPORT ORGANIZATION

This synthesis report is divided into ten chapters.

- Chapter 1 introduces the subject of fixed scour monitoring instrumentation for bridges and includes the purpose of the synthesis, the literature and data sources that were used, and the report organization.
- Chapter 2 includes a general overview of the topic, establishing the fundamental issues related to fixed scour monitoring instrumentation. It includes key terminology, and a summary of the findings from the surveys.
- Chapter 3 is an overview of the bridges being monitored in the United States.
- Chapter 4 provides details on experience with fixed scour monitoring systems.
- Chapter 5 discusses the data obtained from the installations. Sample data may be found in Appendix D.
- Chapter 6 includes information on scour monitoring system locations that have recorded scour depths.
- Chapter 7 has case studies on existing sites. There is also consideration given to potential sites for future monitoring.
- Chapter 8 discusses the national scour database and how information from fixed scour monitors may be incorporated into a national database.
- Chapter 9 discusses recommended improvements, and needs of the equipment to be used at future scour monitoring sites. This includes suggestions and solutions that were obtained during this study. Information on current guidelines may be found in Appendix F.
- Chapter 10 discusses future scour research needs associated with fixed scour monitoring instrumentation.

CHAPTER TWO

SCOUR MONITORING OVERVIEW AND APPLICATION

OVERVIEW AND BACKGROUND

The Federal Highway Administration (FHWA) reports there are approximately 590,000 highway bridges in the U.S. National Bridge Inventory. Of these, about 484,546 bridges are over water (4), with over 26,400 of them having been declared scour critical. A bridge is considered scour critical when its foundations have been determined to be unstable for the calculated or observed scour condition.

Three FHWA Hydraulic Engineering Circulars (HEC) are the guidelines for bridge scour, stream stability, and scour countermeasures: HEC-18, *Evaluating Scour at Bridges* (5) provides guidance for the design, evaluation, and inspection of bridges for scour; HEC-20, *Stream Stability at Highway Bridges* (6) provides instruction on the identification of stream instability problems at highway stream crossings; and HEC-23, *Bridge Scour and Stream Instability Countermeasures – Experience, Selection, and Design Guidance* (3) provides guidelines for the various types of scour countermeasures. For conducting new or rehabilitation designs for bridges, both HEC-18 and HEC-20 are used. Countermeasure solutions may be developed when there are concerns with regard to scour or stream stability.

This chapter includes a general background and the resources relative to the state-of-the-art in bridge scour monitoring technology. The most recent guidance from FHWA on scour monitoring instrumentation may be found in HEC-23 (3). More details on the earlier types of fixed scour monitors may be found in the NCHRP report and instrumentation manuals for Project 21-03 (1,7,8).

Scour countermeasures, as defined in HEC-23, are "measures incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems."

Based on their functionality, HEC 23 categorizes scour countermeasures into three general groups – hydraulic, structural, and monitoring. Hydraulic countermeasures include both river training structures that modify the flow, and also armoring countermeasures that resist erosive flow. Structural countermeasures consist of modifications of the bridge foundation. These may be classified as foundation strengthening, or pier geometry modification. Monitoring countermeasures may be fixed instrumentation, portable instrumentation, or visual monitoring.

THE SCOUR MONITORING ALTERNATIVE

HEC-23 contains the most recent information on scour monitoring, and defines scour monitoring as "activities used to facilitate early identification of potential scour problems. Monitoring could also serve as a continuous survey of the scour progress around the bridge foundations." There are limited funds to replace or repair all the scour critical and unknown foundation bridges, therefore HEC-23 states that an alternative solution is to monitor and inspect the bridges following high flows and storms. A well-designed monitoring program provides an efficient and cost-effective scour countermeasure.

Recommended in HEC-23 are three types of scour monitoring: fixed instrumentation, portable instrumentation, and visual monitoring. Fixed monitors are placed on a bridge structure. The recommended fixed monitors include magnetic sliding collars, sonar monitors, float-out devices, and tilt and vibration sensors. Portable instrumentation monitoring devices can be manually carried, used along a bridge, and transported from one bridge to another. Portable instruments are more cost-effective in monitoring an entire bridge or multiple bridges than fixed instruments; however, they do not offer a continuous watch over the structures. It is often dangerous for individuals to take measurements during a storm event. The allowable level of risk affects the frequency of data collection using portable instruments. Examples of portable instruments are sounding rods, sonars on floating boards, scour boats, and scour trucks. Visual inspection monitoring may be performed at standard regular intervals, and may include increased monitoring during high flow events (flood watch), land monitoring, and/or underwater inspections. The scour hole that forms during a high-flow event is often infilled during the receding stage as the stream flow returns to normal. This "scour-and-infill" cycle is neither detected using portable devices nor during measurements taken by divers after a storm.

A bridge may have one or more types of scour monitoring techniques that also can be used in combination with other hydraulic or structural scour countermeasures. Scour monitoring may be a permanent or temporary interim countermeasure.

FIXED INSTRUMENTATION AND SCOUR MONITORING

According to the FHWA guidelines, existing bridges found to be vulnerable to scour, should be monitored and/or have scour countermeasures installed. FHWA's HEC-18 (5) first recommended the use of fixed instrumentation and sonic fathometers as scour monitoring countermeasures in their Second Edition (1993). Two of the fixed scour monitoring instruments discussed in this report were developed under the TRB NCHRP Project 21-3, *Instrumentation for Measuring Scour at Bridge Piers and Abutments* (1). The purpose of that project was to study devices that measure and monitor maximum scour at bridges. The project developed, tested, and evaluated methods both in the laboratory and in the field. The NCHRP project extensively tested and recommended two systems – the sonic fathometer and the magnetic sliding collar devices. Each of these fixed instruments measures and monitors scour. Additional fixed scour monitoring systems that were tested under this project included sounding rods and other buried devices.

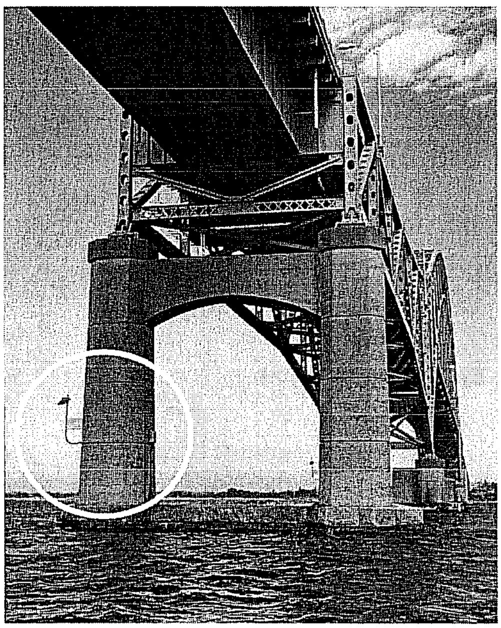


FIGURE 1 Scour monitoring system mounted to a pier on the Robert Moses Causeway over Fire Island Inlet (*circled*)

The sonar scour monitors are mounted onto the pier or abutment face (Figures 1 and 2) to take streambed measurements, and each is connected to a data logger (Figure 3). The sonar instrument measures distance based on the travel time of a sound wave through water. The data logger controls the sonar system operation and data collection functions. The data logger is programmed to take measurements at prescribed intervals. These instruments can track both the scour and refill processes. Some of the survey respondents in this study took the research recommendations and custom-designed scour monitoring systems that met difficult site-specific requirements and developed programs for the monitoring of these bridges that satisfied FHWA and state criteria.

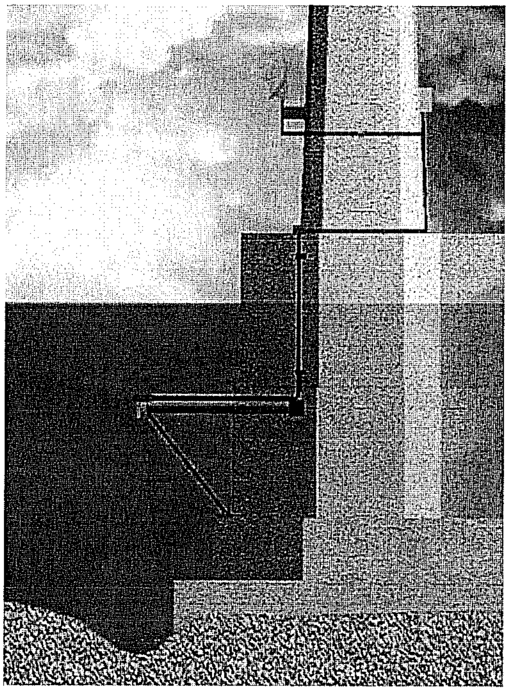


FIGURE 2 Schematic of a sonar scour monitoring system over Fire Island Inlet

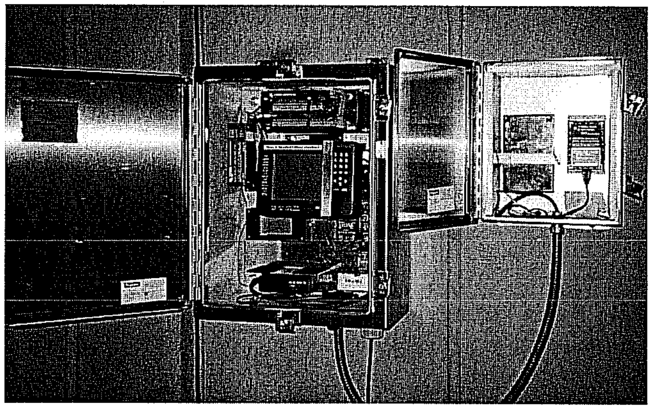


FIGURE 3 Scour monitoring datalogging system

Magnetic sliding collars (Figure 4) are rods that are attached to the face of a pier or abutment. The rods have a collar that is placed on the streambed, and if the streambed erodes, the collar moves down into the scour hole. The depth of the collar provides information on the scour that has occurred at that particular location. Sonar scour monitors may be used to provide a timeline of scour, whereas magnetic sliding collars can only be used to monitor the maximum scour depth.

The sounding rods are manual or mechanical devices (rods) that are used to probe the streambed. These were susceptible to streambed surface penetration in sand bed channels. This influences their accuracy. The other buried devices may be active or inert buried sensors or transmitters.

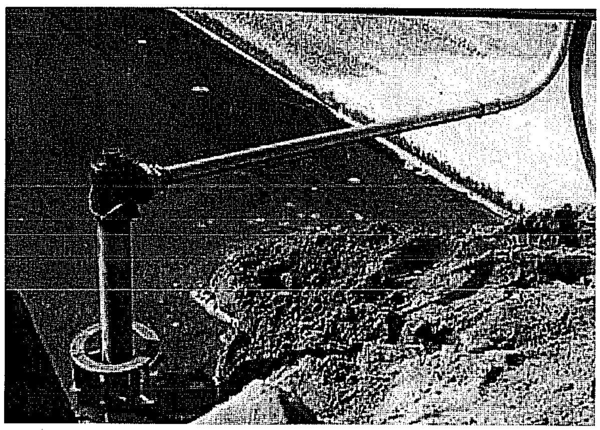


FIGURE 4 Sliding collar installation

Subsequent to the NCHRP project, two additional fixed monitors were developed and installed – float-out devices, and tilt and vibration sensors. Float out devices are buried at particular locations near the bridge's substructure (Figure 5). If scour develops, the devices float up and each transmits a signal, only measuring the particular depth where each was buried. These are particularly easy to install in dry riverbeds, during the installation of an armoring countermeasure such as riprap, and during the construction of a new bridge. Tilt (Figure 6) and vibration sensors measure movements of the bridge.

Data from any of these fixed instruments may be downloaded manually at the site, or may be telemetered to another location. A scour monitoring system at a bridge may use one of these devices, or include a combination of two or more of these fixed instruments all transmitting data to a central control center. These four types of scour monitors are being used in a wide variety of climates and temperatures, and in a host of bridge and channel types throughout the United States. Fixed scour monitors are in use on bridges from Florida to Maine and from Alaska to Hawaii.

FIGURE 5 Float-out device

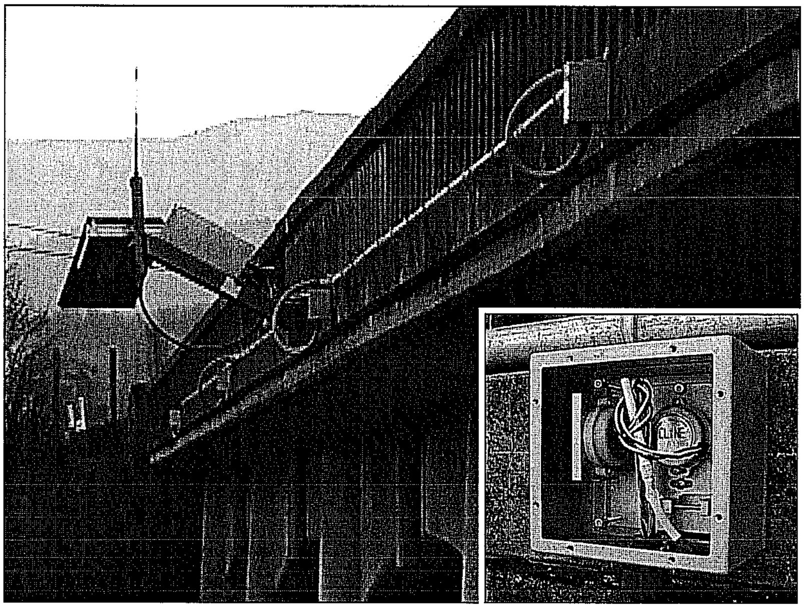


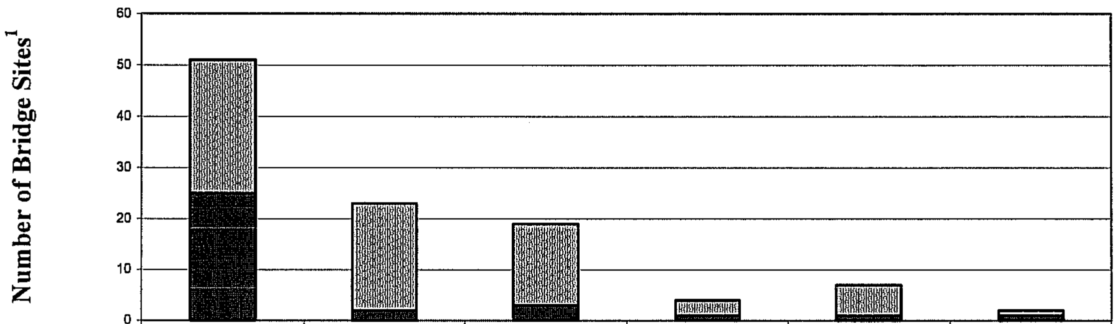
FIGURE 6 Tilt sensor installation with detail of the sensor

SUMMARY OF FIXED SCOUR MONITORING INSTALLATIONS

A total of 93 bridges were found to use fixed scour monitoring instrumentation in the United States. These were identified through the synthesis survey, a literature search and other sources. Figure 7 shows the number of bridge sites for each type of scour monitoring instrument. The sonar scour monitoring system is the most commonly used device, at 51 bridge sites. The magnetic sliding collar and float-out devices are next, with 23 and 19 sites respectively. Brisco monitors, and tilt and piezoelectric film sensors had few installations. Although sonar monitors were installed at the largest number of bridge sites, an evaluation of the total number of scour monitoring devices showed that the float-out devices have the largest number of devices installed. Float-outs are less expensive to manufacture and usually to install, and often numerous devices are placed near the bridge substructure. The other types of devices are usually one or per pier location. Often these are only one device per bridge. Figure 8 shows the total number reported for each type of scour monitoring device. There were 134 float-outs installed or to be installed. Sonar devices were second, with 114 in total. The number of sliding collars and tilt sensors were 36 and 37 devices respectively.

A sample survey may be found in Appendix A, and a detailed listing of the survey responses in Appendix B. In order to summarize some of the findings from the surveys, a matrix has been included (Table 1). This matrix highlights some of factors that should be considered when deciding which type of fixed scour monitoring instruments works best for your site. These factors are discussed in Chapter 3.

Figure 7 Total Number of Bridge Sites with Fixed Scour Monitoring Instrumentation

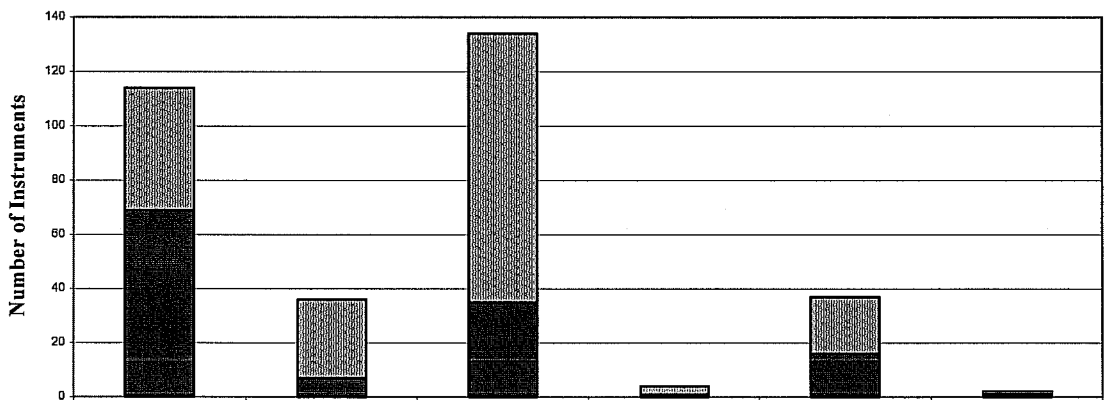


	Sonar	Sliding Collar	Float-Out	Brisco	Tilt	Piezoelectric Film
Literature Search	26	21	16	3	6	1
Synthesis Survey	25	2	3	1	1	1

Type of Instruments

1. Number of bridge sites utilizing that particular instrument. Some sites reported more than one type of instrument at the same bridge.

Figure 8 Total Number of Fixed Scour Monitoring Instruments



	Sonar	Sliding Collar	Float-Out	Brisco	Tilt	Piezoelectric Film
Literature Search	45	29	99	3	21	1
Synthesis Survey	69	7	35	1	16	1

Type of Instruments

Table 1 BRIDGES WITH FIXED SCOUR MONITORING SYSTEMS MATRIX[1]						
SITE CONDITIONS	FIXED SCOUR MONITORING SYSTEM[2]					Total
	Sonar Sensors	Magnetic Sliding Collars	Tilt Sensors	Brisco Sensors	Float-Out Devices	
BRIDGE GEOMETRY						
Substructure Type						
Abutment	1					**1**
Pier	11	3	1	1	3	**19**
Foundation Type						
Pile	9	2	1		3	**15**
Spread Footings	3	1		1		**5**
Drilled Shafts	1					**1**
Unknown						**0**
WATERWAY CHARACTERISTICS						
Waterway Type						
Tidal	5					**5**
Riverine	6	3	1	1	3	**14**
Flow Habit						
Ephemeral						**0**
Intermittent	3				1	**4**
Perennial but flashy	1	1	1		1	**4**
Perennial	7	2		1	1	**11**
Water Depth						
< 10 ft (< 3m)	3	1	1	1	2	**8**
10 - 30 ft (3.1 - 9.1 m)	5	1				**6**
31 - 50 ft (9.2 - 15.2 m)	2					**2**
51 - 75 ft (15.3 - 22.9 m)	1				1	**2**
76 - 100 ft (23 - 30.5 m)						**0**
SOIL CONDITIONS						
Clay	4	1			2	**7**
Fine Sand/Silt	8	3	1		1	**13**
Coarse/Medium Sand	7	1	1		2	**11**
Gravel	3	2			1	**6**
Cobbles	1	1				**2**
Organics	1					**1**
Riprap	3					**3**
EXTREME CONDITIONS						
Debris	6	3	1	1	1	**12**
Extreme temperatures	1					**1**
Sediment loading	4	1	1		1	**7**
Ice flows	4	2		1		**7**
Air entrainment						**0**
High velocity flows	8	2	1	1	1	**13**
POWER SOURCE (for monitoring system)						
Solar	7		1		2	**10**
Commercial	6	2	1		2	**11**
Back-up battery	3					**3**
ACCESS (to monitoring system)						
Security clearance	1					**1**
Lane closures	2	1			1	**4**
Boat	6	1			1	**8**
Keys to doors/gates	2	1			1	**4**
DATA RETRIEVAL (from monitoring systems)						
Locally	4	3		1		**8**
Telephone	5		1		1	**7**
Cellular	2				1	**3**
Satellite	2					**2**
INSTALLATION EXPERIENCE BY STATE						
	AK, CA, FL, IN, MD, NC, NV, NY, KS	IN, NY	CA	NY	AL, CA, NV	

1. Results based on 13 complete surveys that indicated the use of fixed scour monitoring systems at specific bridge sites. Additional bridge sites were reported but not in full detail. For a complete list of reported bridge sites with fixed scour monitoring instrumentation, refer to Appendix C.
2. Vibration sensors, sounding rods, buried/driven rods and piezoelectric polymer films were also in the survey. However, none of the survey respondents reported using these fixed scour monitoring systems.

OVERVIEW OF BRIDGES BEING MONITORED

OVERVIEW OF SURVEY AND LITERATURE RESULTS

This overview of bridges with fixed scour monitoring systems includes data from the respondents of the survey, as well as information obtained from the literature search and other sources. This study identified 25 states that have installed fixed scour monitoring systems on one or more of their highway bridges. This includes systems that are currently active, those that are no longer in service, and states with plans to install monitoring systems. These states are listed and shown on a map of the United States in Figure 9. A complete list of the bridges that have been identified may be found in Appendix C.

Thirty states responded to the scour monitoring survey. Florida and New York, submitted several responses from different districts and agencies, therefore a total of 36 completed surveys were received. A list of the respondents may be found in Appendix G. Of the respondents, 18 reported using instrumentation for scour monitoring, and the other 18 stated they did not. The group that used instrumentation included 13 that used fixed instrumentation, while seven employed portable instrumentation.

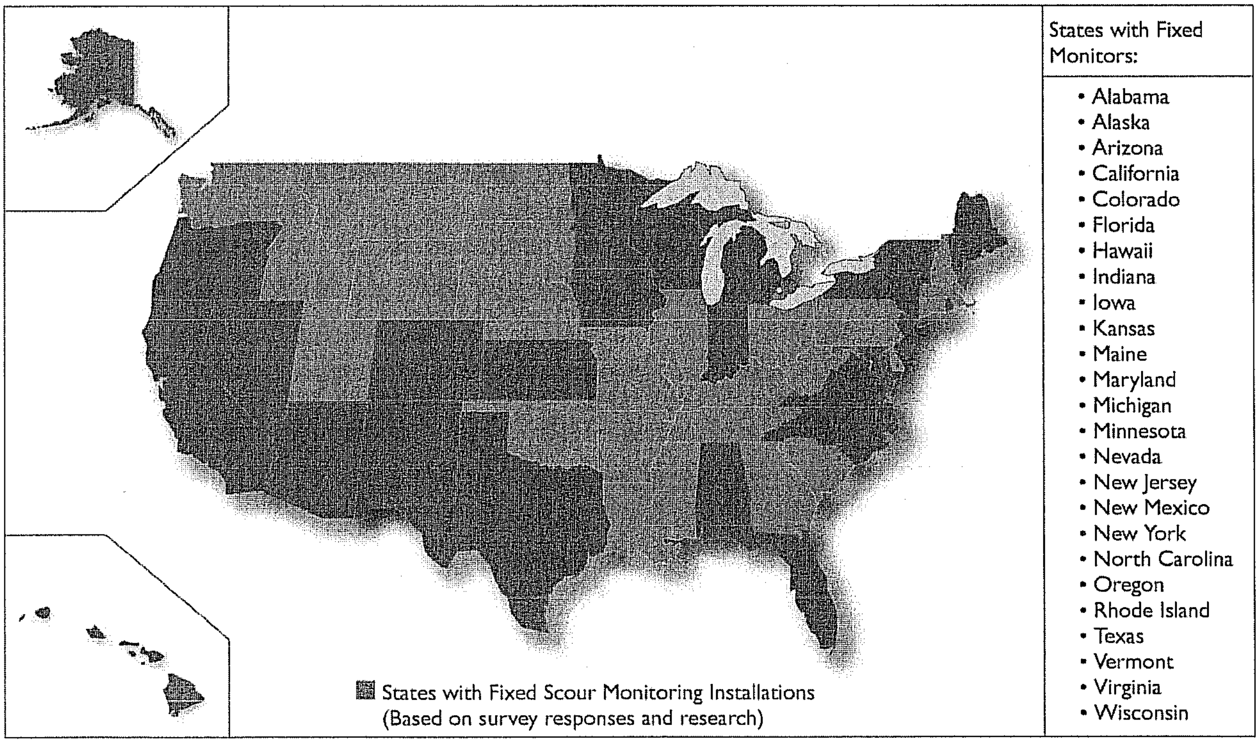


FIGURE 9 States with fixed scour monitoring installations

The states that use fixed scour monitoring instrumentation were asked about their general scour monitoring experience, and to complete specific detailed questions on at least one sample bridge site.

They were also asked to provide additional, less detailed information on other bridge sites they are monitoring. Completed surveys were received from a total of 13 sample bridge sites. These surveys were from 10 different states. The 13 sample bridges were all state owned and maintained by their DOTs, with two exceptions. One bridge is owned by FHWA and is maintained by Maryland State Highway Administration, and the second bridge is owned by the New York State Thruway Authority.

The 13 monitored bridge sites that responded to the survey reported a wide range of conditions. Table 2 includes a list of the 13 bridges with statistics on each location. The average daily traffic (ADT) for the monitored bridges ranged from 2,650 to 175,000 vehicles per day. The mean ADT was 29,472, and the median was 9,000 vehicles per day. The total length of the bridge varied from small to long span bridges. The smallest bridge was 23 m (75 feet) long, while the longest was 3,921 m (12,865 feet) in length. The mean bridge length was 660 m (2,167 feet), and the median was 253 m (830 feet). The bridges being monitored were constructed between 1930 and 1985. The mean and median years were 1959 and 1962 respectively. The scour monitors were installed between 1992 and 2002.

All the owners reported a history of scour at the bridge site that was being monitored. Twelve of the bridges being monitored are on pile foundations, while one is on spread footings. The foundation depths were all known, with 10 reporting as-built depths, and three the design depths. Ten reported that there were borings and/or soil and rock data available for their bridge site.

SITE SPECIFIC FACTORS AND THE DECISION-MAKING PROCESS

When deciding which fixed scour monitoring system to use, many factors need to be considered. These considerations range from waterway characteristics to bridge geometry to soil conditions. The decision-making process requires the multi-disciplinary effort of hydraulic, structural, geotechnical engineers. FHWA HEC-23 (3) contains a table to aid in the selection of a fixed scour monitoring system. It includes both advantages and disadvantages of various conditions as they pertain to fixed scour monitoring. In Chapter 2 of this study, Table 1 is a matrix which summarizes some of these site-specific factors from the surveys. The following is a discussion of the conditions that affect the selection of an appropriate fixed scour monitoring system.

(To the Synthesis Panel: There were several states that have indicated they will submit data on the sites they monitor. We would like to take that information and add that to the sites already received and see how it compares with the HEC-23 table)

Bridge Geometry

The bridge owners reported that 93% of the structures monitored with fixed instruments were piers. Complex pier geometry can make it difficult to mount equipment directly onto the structure. Protrusions from footings or steel sheeting may block monitor readings. As-built bridge plans or measurements from divers can provide important information for the design of the components of the scour monitors. In the case of sonar scour monitors, adjustable mounting brackets have been

Table 2 Bridge Specific Data
Sample set of 13 surveyed bridges with fixed scour monitors

State	Bridge Name	Type(s) of Fixed Scour Monitors	ADT	Year Built	Year Rebuilt	Bridge Length (m)	Bridge Length (ft)	NBIS Item 113	Foundation Type	Known Foundation Depth
Alabama										
	US - 82	1 Float-Out	9,000	1962	N/A	345	1,133	N/A	Pile	As-Built Depths
Alaska										
	Knik River	1 Sonar	3,407	1975	N/A	154	506	7	Pile	As-Built Depths
California										
	Santa Clara River	1 Sonar, 16 Tilt Sensors, 32 Float-Outs	N/A	1930	1965	558	1,830	3	Pile	As-Built Depths
Florida										
	John's Pass Bridge	2 Sonars	N/A	1971	N/A	253	830	3	Pile	As-Built Depths
	SR-105 & SR A1A	8 Sonars	N/A	1949	N/A	37	120	5	Pile	As-Built Depths
Indiana										
	US-52 over Wabash River and SR-43	1 Sonar, 1 Magnetic Sliding Collar	19,498	1969	1984	305	1,002	8	Pile	Design Depths
Kansas										
	Amelia Earhart Bridge (US 59)	2 Sonars	8,960	1938	N/A	762	2,500	5	Pile	Design Depths
Maryland										
	Woodrow Wilson Memorial Bridge (US 495)	5 Sonars	175,000	1961	2006	1,798	5,900	5	Pile	As-Built Depths
New York										
	Wantagh Parkway over Goose Creek	4 Sonars	129,000	1930	1998	164	537	6	Pile	Design Depths
	Route 262 over Black Creek	1 Brisco	N/A	1949	1981	23	75	3	Spread Footing	As-Built Depths
	NYS Thruway over Cattaraugus Creek (US 90)	6 Magnetic Sliding Collars	31,730	1954	1992	203	667	7	Pile	As-Built Depths
Nevada										
	SR 159 over Red Rock Wash	2 Sonars, 2 Float-Outs	2,650	1985	N/A	61	200	5	Pile	As-Built Depths
North Carolina										
	Herbert C. Bonner (NC-12)	4 Sonars	5,100	1962	N/A	3,921	12,865	3	Pile	As-Built Depths
		Median	**9,000**	**1961**	**1988**	**253**	**830**	**5**		
		Mean	**29,472**	**1957**	**1989**	**660**	**2,167**	**5**		

developed for flexibility during the installation and to allow the monitors to take readings beyond the footing or any steel sheeting.

Waterway Type, Flow Habit, and Water Depth

Understanding the waterway characteristics will enable the bridge owner to determine what type of information is needed and which monitors would best work at the site. The type of waterway, whether it is tidal or riverine, is an important consideration. Both flood and ebb conditions need to be taken into account in the tidal environment. The instrumented bridge sites included 38% in tidal environments. Scour monitors may be placed on both sides of the bridge to monitor the scour conditions due to incoming and outgoing tides.

The flow habit is another factor to evaluate. With ephemeral and intermittent waterways, the streambed is dry some or most of the time. Perennial waterways always have some flow. Both types of conditions affect the type of installation procedures that may be used to place a monitoring system at the site. The bridge owner also needs to assess whether continuous monitoring is needed and practical. Certain monitors such as sonar and sliding collars, yield a continuous set of data. Other types of monitors such as float outs are activated only when certain scour depths are reached. Three of the survey respondents experienced intermittent conditions and utilized a combination of continuous and non-continuous monitors. When perennial conditions were present, eight out of nine survey respondents employed continuous monitors only.

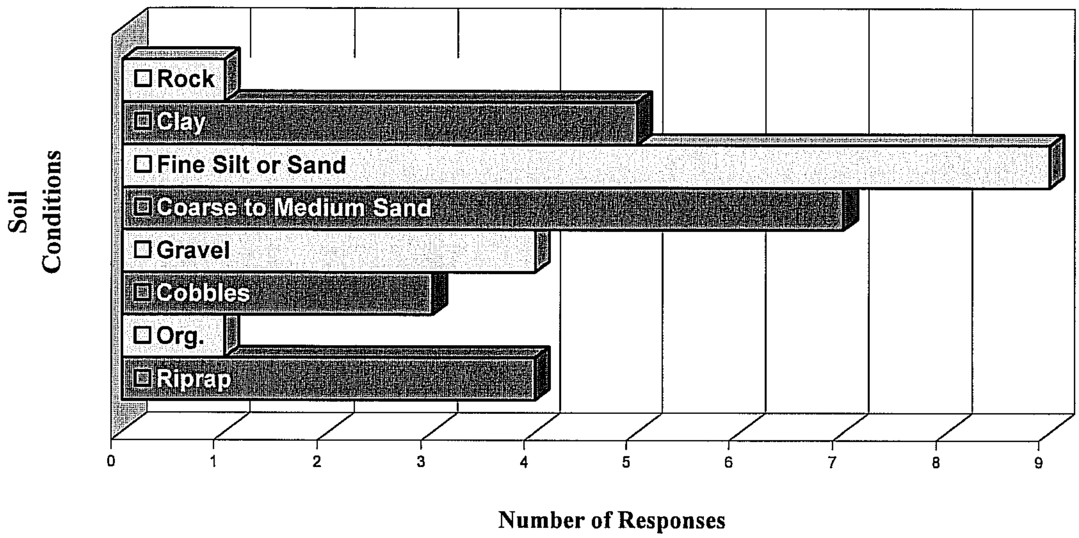
Water depth can be another limiting factor. In deeper waterways, it may be expensive and difficult to bury monitors. Driven rods may also not be practical in deeper channels due to long, unsupported lengths of the rods.

Soil Conditions

The type of soil being monitored is important. Clays tend to erode at a slower rate than sands. Clays may reach their maximum scour depths after numerous events, while sands may reach the maximum scour depths in one event. Sands are also more prone to infilling of a scour hole after an event. Infill is often less dense and does not have the same capacity as the original soil. Infilling is difficult to detect through diving inspections, or occasional field measurements. The scour hole usually fills in within a short period of time following a storm event. A majority of the survey respondents had sands as the predominant soil and used fixed scour monitors with continuous data recording capabilities (Figure 10). Two of the survey respondents noted they had observed the occurrence of infill at their bridge sites.

The type of soil present is also a good indicator of where monitors should be placed with relation to the structure. In clays, the greatest scour occurs behind the pier as it faces the flow. In sands, the greatest scour is located adjacent to the pier.

Figure 10 Soil Conditions at Scour Monitoring Locations



Bar graph is based on a sample set of 13 completed surveys that indicated the use of fixed scour monitors.

Scour History

All of the survey respondents who used fixed scour monitoring systems reported a history of scour at their bridge sites. The scour observations and evaluations were used in the decision-making process to determine the number and locations of the individual monitoring instruments.

Power

Fifty-seven percent of the survey respondents used commercial power. This may be accomplished by tapping into the electrical system at the bridge, particularly at movable bridges. The remaining 43% used solar power. Respondents indicated that solar power was utilized at remote bridge crossings where power supplies were not readily available, or on long span bridges to reduce the cost of long conduit runs. Batteries were used as temporary back-ups at numerous sites.

Extreme Conditions

Survey respondents indicated that high velocity flows, debris, ice forces, sediment loading, and/or severe water temperatures were forms of extreme conditions that were present at their bridge sites. However, indicates that debris (26%) and ice (13%) forces caused the most damage and interference to the scour monitoring systems. Based on survey responses, the extent and frequency of damage was often not anticipated by the bridge owner. This resulted in much higher maintenance and repair costs than were anticipated. One respondent indicated that repair costs were double what they had budgeted. Numerous cases were also reported where new instruments had to be installed after high velocity flows, debris, and/or ice forces caused the existing instrument to break off from the structure.

When there are extreme conditions, the materials used to produce the scour monitoring instrumentation need to be robust. Many survey respondents indicated that this is an area of concern because certain current materials do not last long enough when severe conditions are present

Figure 11 Site Conditions at Scour Monitoring Locations

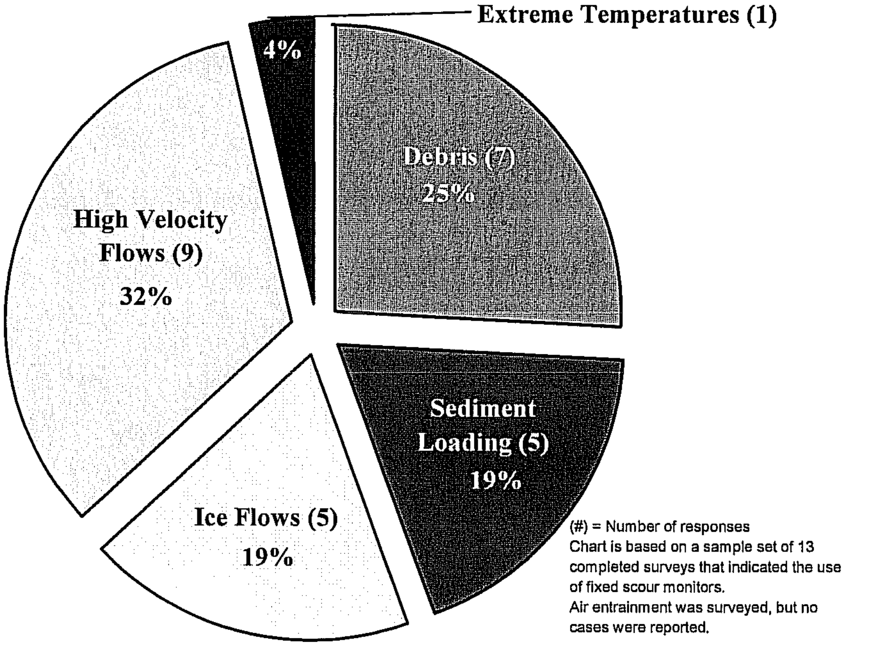
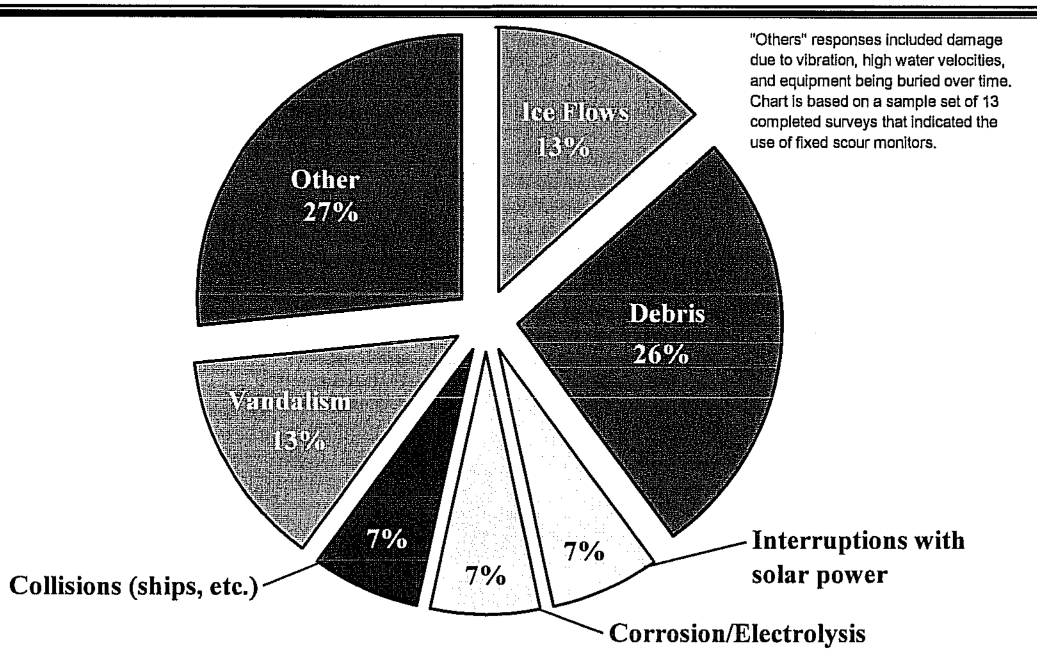


Figure 12 Site conditions that caused interference or damage to the fixed scour monitoring systems



Access and Vandalism

Complex access requirements can make it difficult to install, maintain, and repair a fixed scour monitoring system. Additional parties or equipment may be required, such as divers or boats, both to install, and later to access the system. These items must be given serious consideration especially when planning a maintenance and repair program and budget. Examples of access limitations include: security clearances, traffic lane closures, boats, keys to doors or gates, and under bridge inspection trucks. Survey responses showed that 47% of the scour monitoring systems required access by boat.

Access is important, but if a scour monitoring system is too readily accessible, vandalism may occur. Thirteen percent of the respondents indicated that damage to their scour monitoring systems was due to vandalism. These unexpected repairs increased the cost of maintaining the system. One survey respondent reported that monitoring was discontinued because of repeated vandalism.

RAILROAD BRIDGES

Inquiries were made regarding the use of fixed scour monitoring systems on railroad bridges in the United States, but none were identified. One of the railroad owners described their procedures regarding monitoring and scour critical bridges. Their monitoring is most frequently visual (inspection) monitoring. Many railroads have procedures that require trains to be operated at restricted speeds over scour critical bridges during periods of heavy rain. Railroad dispatchers can control the trains via radio. They may instruct their trains to reduce their speeds, or stop and inspect a bridge. The instrumentation commonly used by railroads is high water detectors. These will sense water over the track and this information is transmitted to the train signal system. This warning device reports when the water surface elevation has reached the level of the tracks. The railroads often have inspection programs during and after major storms.

CHAPTER FOUR

EXPERIENCE WITH SCOUR MONITORING SYSTEMS

The survey asked bridge owners various questions about their experiences with fixed scour monitoring instrument systems. This chapter includes a summary of their responses, as well as trends from the survey and the literature research. The detailed responses of the survey respondents experience and opinions may be found in Appendix B.

REASONS FOR INSTALLATION OF THE MONITORING SYSTEM

The bridge owners were asked to indicate why they installed fixed scour monitors at their bridges. Ten of the 13 survey respondents stated that their bridges had scour critical ratings. Three indicated research projects, one a bridge replacement, and another, an observed scour hole.

Other factors that contributed to their decision to use fixed scour monitors at their bridge sites included the importance of the transportation system, scour evaluations, a history of scour, a pier failure, spread footings, short piles at the piers, high water velocities, public safety concerns, a need for continuous monitoring during storms, observations during routine inspections, the bridge is scheduled to be replaced, stage construction requirements, the difficulties involved with hydraulic or structural countermeasures, the relatively low ADT, a potential headcut from downstream controls, and the research team insisted on monitoring.

As shown in Chapter 3, Table 2, the NBIS Item 113 Rating for Scour Critical Bridges ranged from 3 to 8 on the sample bridges that are being monitored. There were only four ratings of 3, which indicates that a bridge is scour critical. The other bridges were rated 5 to 8, which are not scour critical ratings. It is not known whether additional scour countermeasures were installed at these bridges in order to improve their scour critical status. Less than half indicated that the scour monitoring data obtained had been useful for changes or verification of their bridge scour ratings. Alaska mentioned that the scour monitors had identified large dune bedforms and season sediment "starvation". California stated that the data confirmed that the scour did not adversely impact that particular bridge.

OFFICE RESPONSIBLE FOR MONITORING

The office responsible for scour monitoring varied, but was most often the structures or maintenance group of the state DOT. Others that were mentioned included the state hydraulics group, universities, the USGS and consultants.

PURCHASE, INSTALLATION, MAINTENANCE AND REPAIR COSTS

The bridge owners provided some information on the costs of installation. This may be found in Appendix B. The prices ranged from $8,000 to $40,000 per monitor location. There was not enough information obtained to provide prices for the different types of fixed scour monitors. Installation costs can vary greatly due to the different site conditions. Scour monitors may be installed at certain sites by the state maintenance group with equipment they own. Other more complicated sites may require specialized contractors and construction equipment to install the devices. *(Further investigation will be done for the second draft of this report.)*

Maintenance and repair costs were only given by one respondent. The general comments on maintenance ranged from modest to expensive. Repair costs were estimated to be expensive, particularly for divers for the reinstallation of sonar monitors. Comments included the need for a commitment to maintain the equipment and also a maintenance contract with a firm familiar with the equipment. Traffic conditions were also cited as a difficulty in maintaining the equipment.

EVALUATION OF BENEFITS

The majority of states mentioned safety for the traveling public as the main benefit of scour monitoring systems. Additional benefits included a reduced number of underwater and/or regular inspections, early identification of problems prior to a diving inspection, and insight into site-specific scour processes. The system is a component of comprehensive program that includes a plan of action for emergency conditions and underwater inspections. A point was made that the system serves to warn of a problem at the bridge site, but response time and engineering judgment by those persons responsible for the bridge are the most important part of the alarm system.

VERIFICATION OF SCOUR PREDICTION

The bridge owners were asked if their scour monitoring data had been useful in verifying scour prediction equations.

Hawaii DOT is funding a project that uses scour monitoring data to evaluate the accuracy of some of the FHWA HEC-18 (5) scour equations. This work is being conducted by the University of Hawaii in Manoa, Honolulu. In addition to their surveys, they submitted a paper that will be presented at an ASCE Conference on Mechanics and Materials in June 2005. The title is "A Validation Study of the Empirical Bridge Scour Equations", and a copy may be found in Appendix E. Scour monitors were installed at two bridges in Hawaii. In January 2004 a storm was recorded by the sonar monitors at one bridge, and the field data was used to examine the validity of the existing scour equations. The results showed that the predicted scour depth at this bridge based on the existing empirical equations could be more than four times larger than the recorded scour depth in the field. They note that this is a preliminary study, and they recommend more field monitoring and data collection at more bridge sites.

The remainder of the respondents did not provide any data in this regard, but their observations on this subject are described below.

Alaska stated that their scour monitoring data has fostered a number of USGS reports. Their analysis was not yet complete at the time of this study.

Maryland reported that to date there has been no significant scour recorded at any of the five piers being monitored. The velocity meters readings show that velocities have been low over the monitoring period, from 1999 to present. They note that this has been useful in indicating that the bridge is stable, that bridge closures have not been necessary, and to ensure the safety of the traveling public.

Florida reported that they had observed the tidal scour and infill processes. Their scour monitoring instruments have recorded the movement of loose soil, and its redeposition by the tidal change currents.

The New York State Thruway Authority reported that a change in the monitored streambed elevation prompted further investigation of potential scour at the bridge. The results showed that the footing of the bridge was not exposed.

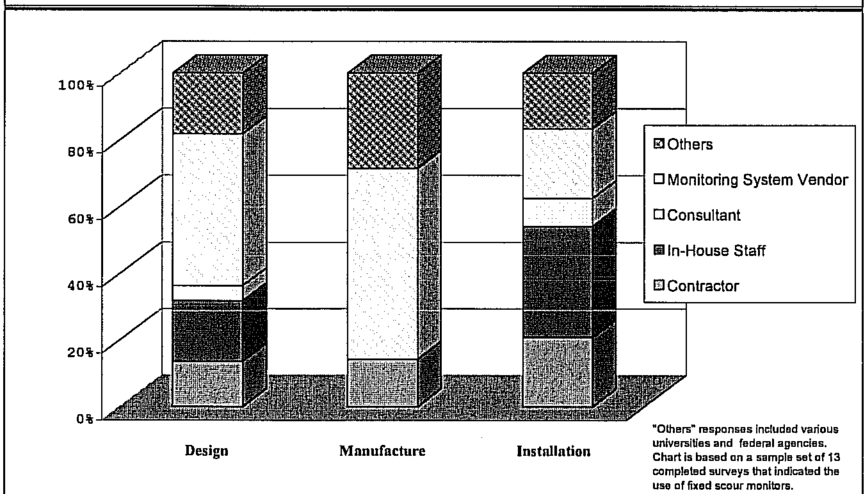
California reported that tilt meters have been able to track the daily thermal movements, and the influence of construction activities adjacent to the bridge site. This site experienced record flows in January 2005, but no alarms or excessive movements were tracked. The float-out devices at the site were not activated.

INSTALLATION EXPERIENCE

The type of contract used to install the scour monitoring systems varied and included bridge scour countermeasures, bridge rehabilitation, research, USGS research, and emergency scour conditions.

Figure 13 shows which parties were involved with the design, manufacture, and installation of the scour monitoring systems. The groups included the owner (in-house department), monitoring system vendor, contractor, consultant and others. The design and manufacture of the systems was done primarily by the monitoring system vendor, whereas the installations were done mostly in-house by the bridge owners.

Figure 13 Parties involved in the design, manufacture, and installation of fixed scour monitoring systems



Additional Scour Countermeasures

According to FHWA HEC-23, scour monitoring may be used in conjunction with other scour countermeasures. Five sites reported the use of additional scour countermeasures at their bridges. These different countermeasures at four of the site: riprap protection, stone filled steel sheet piling around the piers, lateral stiffening and bracing between the pier bents, and portable sonar monitors to confirm the measurements taken by the fixed scour monitoring devices. The fifth site was in North Carolina and reported extremely severe conditions. Some areas near the bridge had scoured and filled as much as 16.5 m (54 ft). Water velocities were in the 3.7 to 4.6 mps range (12 to 15 fps). Numerous scour countermeasures were employed at this bridge and they included armor stone around the bents, new steel helper -bents, concrete cylinder pile helper bents, gabion mats, A-Jaxs concrete armor units, and sand bag scour protection.

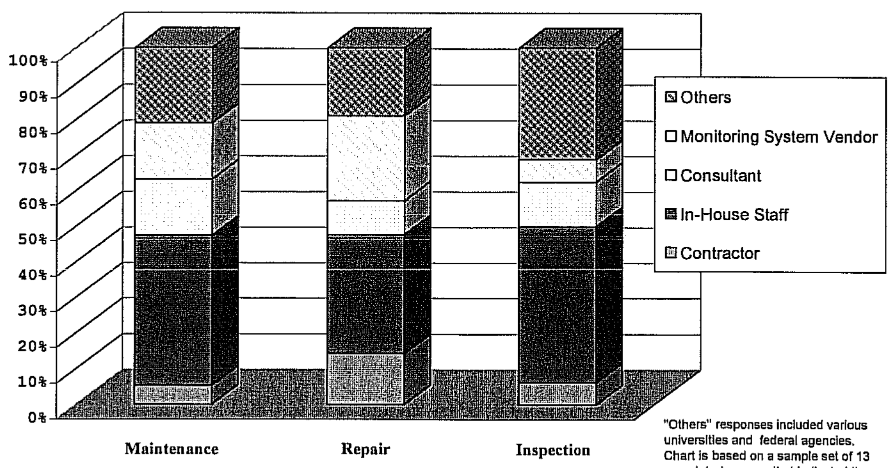
Additional Instrumentation

Few additional measurement instruments were reported at the fixed scour monitoring installations. The most common were water stage sensors and temperature sensors. Velocity meters were also reported, as were inclinometers and wind sensors. Most of these sensors were integrated into the scour monitoring system. The temperature sensors are used for sound velocity correction for the sonar scour monitoring systems.

CHALLENGES AND PROBLEMS

Problems encountered during installation included difficulties in attaching the brackets to the substructure, working from a boat, climbing the superstructure, and access to the river, traffic lane closure restrictions, budget limitations for staff overtime work, the monitors were difficult to install and required extensive equipment and experienced personnel (Figure 14), radio telemetry interference due to inline cellular telephone tower, and environmental impacts and disposal regulations for the excavation for the float-outs devices.

Figure 14 Parties involved in the maintenance, repair, and inspection of fixed scour monitoring systems



"Others" responses included various universities and federal agencies. Chart is based on a sample set of 13 completed surveys that indicated the use of fixed scour monitors.

Problems and issues after installation included the need for specialized equipment and personnel for maintaining the system; budgets that do not anticipate unscheduled repairs; vandalism; high water velocities that cause excessive strain to the mounting brackets; power, communication and vandalism problems in remote locations; and the need for an instrument bracket that will withstand ice and debris, but is long enough to clear protruding footings.

The various problems and challenges have caused a significant amount of uncertainty as to whether agencies will use fixed scour monitoring systems in the future (Figure 15).

Figure 15 Will your agency use scour monitoring technology in the future?

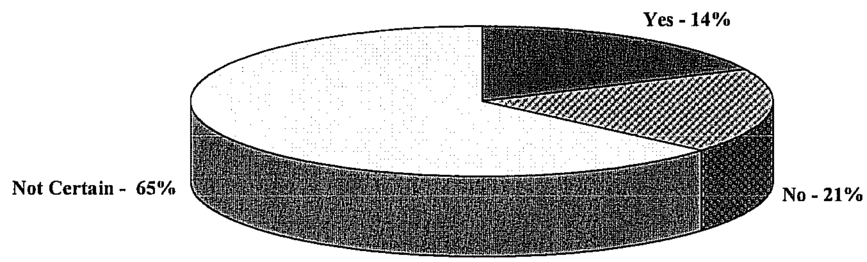


Chart is based on a sample set of 13 completed surveys that indicated the use of fixed scour monitors.

INSTRUMENT RELIABILITY AND LONGEVITY

About 50% of the sites reported that their fixed scour monitoring installations were operational. The remainder reported that the monitoring was discontinued, that the system needed repairs, or was vandalized. A wide variety of factors interrupted or damaged the fixed scour monitoring systems. Figure 12 in Chapter 3 showed the percentages for numerous factors affecting service. The most common problem was the debris flows and accumulation.

Survey respondents were asked to comment on reliability and longevity of their scour monitoring systems. The comments on problems included vandalism, access limitations to replace batteries, marine growth, debris, and damage to the sensor attachments due to high water velocities.

Regularly scheduled maintenance and inspection procedures for their scour monitoring systems were reported by approximately 50% of the respondents. The Florida districts reported that the underwater sonar sensors require maintenance or replacement one to two times per year due to marine growth accumulation.

PROGRAMS, MANUALS, AND GUIDELINES CONCURRENTLY DEVELOPED

Emergency Protocol

An emergency protocol may be set up through a plan of action for a bridge or system of bridges, or through other documents. The respondents were asked to describe what they considered an emergency situation, and what the emergency protocol would be for their bridge site(s). The majority of respondents stated that structural stability analyses were conducted for their bridge piers and abutments, and threshold scour elevations were established that would trigger the emergency protocol, should they occur. Specific water surface elevations, or tropical storm or hurricane watches and warnings were also used to determine if there were emergency situations. Emergency responses to these situations included visual monitoring, increased frequency for downloading the data of the fixed scour monitoring systems, underwater inspections, bridge closures, and the design and installation of hydraulic and/or structural scour countermeasures.

The majority of bridges owners reported that an emergency plan of action, similar to that developed by FHWA, had been established for their monitored bridge sites.

General Protocol

About half of the respondents indicated that they conduct independent checks in order to confirm the validity of the scour monitor readings. These independent checks were most often underwater diving inspections. Portable scour monitoring instrumentation has been used.

Appendix F contains sample programs, guidelines and manuals for fixed scour monitoring systems.

ADVANCEMENTS AND INNVOVATIONS

Automated alarm systems may be installed as part of the scour monitoring systems. They serve to notify the owner, or designated parties, if a scour threshold reading has been obtained. This information may be transmitted through a variety of forms from the bridge, and notification of a designated scour reading may be sent to a pager, telephone, fax, or computer. The respondents indicated that these automated systems were included in about half of their installations, but some of these systems were not activated. Often the owner prefers to have a person download the data in order to check existing conditions.

There were few special innovative features or materials reported. Most of these were in practice during the NCHRP project (1) on fixed scour monitors, but were developed subsequent to that, and are described in FHWA HEC-23 (3). The innovative features reported by the survey respondents included remote downloading capabilities via telephone, water temperature sensors for sound velocity correction on sonar scour monitors, water stage sensors, and radio transmission of data from remote stations to a permanent facility. In channels with high water velocities and/or tidal waters, the use of stainless steel (ASTM 316) or aluminum mountings for the underwater components were reported to be more successful than the PVC used during the NCHRP project on scour monitoring instrumentation (1).

CHAPTER FIVE

DATA COLLECTION AND ANALYSIS

DATA COLLECTION

Frequency of Data Collection

The data collection procedures for the fixed scour monitoring systems varied among the respondents. The survey asked the owners regarding the protocol for several items regarding the data collection. This included the frequency with which the fixed monitors record data, and how often the data is collected and reviewed under normal procedures, and during emergency situations.

The fixed scour monitor instruments that take periodic readings may be programmed for any desired interval. The respondents reported that the intervals for their readings ranged from every 15 minutes to one time per month. Most of the monitors were programmed to take readings one to two times per hour.

The streambed elevation data is typically stored in a data logger and may be collected and reviewed by the owner or his/her designee at any desired interval. This data may be downloaded at the bridge site, or from a remote site via telemetry. The respondents to the survey indicated that the interval at which their data is collected and reviewed under normal circumstances may be daily, weekly or monthly. About half of the responses checked the category "other" and noted that this was done during floods, or as needed.

During emergency situations, the frequency with which data is collected also varied. It included every 15 minutes, hourly, twice daily, daily, and bi-weekly.

Methods of Data Collection

The data may be downloaded and retrieved automatically via telemetry, or at the bridge site. The automatic system may be to a base computer or to a network, and retrieved via an internet connection. The automatic retrieval is the most common system in the installations surveyed. Earlier installations most often involved manual downloading of the data at the bridge sites. The respondents used one of the three systems. The automatic to a base computer was the most frequently used, and the other two systems were about equal is usage.

The data may be downloaded using a landline telephone, cellular telephone, via a satellite connection, or locally at the bridge site. The respondents indicated that the use of the landline telephone and the local download of data at the bridge site were the most frequently used modes. The cellular telephone and satellite connection were not as common, and are usually used when the landline telephone is not available.

DATA ANALYSIS

The type of fixed scour monitoring system employed depends on what kind of information is desired. If a series of streambed elevations over time are of interest, sonars, magnetic sliding collars and Brisco monitors may be used. If a bridge owner is interested only when a certain streambed elevation is reached, float-outs may be employed. For specific information on a pier or abutment, tilt sensors record relative rotation, and vibration sensors measure the movement of the structure. Survey respondents also gathered information on water elevations, velocities, and temperature readings.

Once the data is gathered, it may then be analyzed. Survey respondents indicated that data was typically recorded as either text files or spreadsheets. These types of file formats make it easy for the engineer to analyze large amounts of data. Graphs and plots are simple to generate through a spreadsheet program such as Microsoft Excel. Sample plots were provided by Florida, Maryland, and New York and may be found in Appendix D. The graphs show streambed elevations, water stage elevations, and velocity versus time. All three installations used sonar scour monitors to record continuous sets of data.

If a scour monitoring system is continuously gathering data over a period of months or years, a large amount of data is generated. Data reduction techniques have been employed to view trends over long periods of time. The Wantagh Parkway over Goose Creek in Long Island, New York is one such example. Since 1998, the monitors have recorded the streambed and water stage elevation every hour, twenty-four hours a day. In 2004 the system was refurbished and the new software that was installed was programmed to take readings every half hour. To make the data easier to work with, spreadsheet programs were developed to extract daily and monthly minimum values. Samples of these reduced data graphs are included in Appendix D.

A continuous set of data is available from six of the survey respondents. An additional three indicated that they were not certain if the data is available.

SITES WITH OBSERVED SCOUR DEPTHS

Several states provided information on monitoring sites where scour has been observed and preserved. A summary of this information is included below, and additional details and the data may be found in Appendix D.

All the survey respondents reported that the monitored sites had a history of scour problems. The following states have observed scour since the installation of their fixed scour monitoring systems, or provided their comments and observations.

Alaska

Alaska DOT reported that the fixed scour monitors were helpful in providing insights into site-specific scour processes.

California

FHWA HEC-23 (3) reported on the SR 101 Bridge over the Salinas River near Soledad. This bridge was one of five California bridges instrumented in preparation for El Niño driven storm events in 1997-98. This work was done by CALTRANS with funding from FHWA. This bridge experienced several scour events in February 1998, which triggered threshold warnings. The automated sliding collar dropped 1.5 m (5 ft), and several days later a float-out device buried about 4 m (13 ft) below the streambed was activated.

Florida

The data from the sonar monitors at the John's Pass Bridge has indicated there is loose soil scour and infill by tidal change currents. Sample data for the John's Pass Bridge may be found in Appendix D.

Maryland

The Maryland State Highway Authority (MDSHA) provided scour data for the Woodrow Wilson Memorial Bridge over the Potomac River during Tropical Storm Isabel. This was recorded on September 16-26, 2003 and the data may be found in Appendix D.

New York

General degradation and seasonal infilling have been recorded by the sonar scour monitors at the Wantagh Parkway over Goose Creek site from 1998 to the present. The streambed elevations tend to vary seasonally, with lower elevations during the winter months, and infill during other periods. Lowering of the streambed was recorded during Hurricane Floyd in 1999 and also during various storms. A period of deposition and scour also occurred in the winter of 2003. This was most likely due to pile driving activity at a neighboring bridge site less than a mile away. Sample data for the Wantagh Parkway over Goose Creek Bridge may be found in Appendix D.

Texas

FHWA HEC-23 (3) and the University of Texas (9) reported on observed scour at the U.S. 380 Bridge over the Double Mountain Fork of the Brazos River (ID #360-2-26). This bridge is located about 4 miles west of Rule, in Haskell County. In 1994, the Texas Department of Transportation installed a manual-readout sliding collar device on the bridge. This was done with technical assistance from the NCHRP 21-03 (1) research team and funding by the FHWA.

U.S. 380 Bridge had a history of scour and more than 6.1 m (20 ft) of scour had been reported at the bridge. The support pipe for the sliding collar was driven 5.8 m (19 ft) into the refilled scour hole in the streambed. The sliding collar recorded approximately 1.5 m (5 ft) of scour during the first significant storm event. It is not known whether the system is still operational since it is a manual readout device, the University of Texas report notes that maintenance personnel do not routinely visit the site to collect the data.

CASE STUDIES

EXISTING SITES

Scour Monitoring of Three Long Island Bridges

A partial bridge pier failure due to scour resulted in the investigation of the cause, the design of repairs, and the preparation of a plan of action. This event led to the development of a scour monitoring program that uses sonar scour monitors to ensure stability of the bridge and the safety of the traveling public. Twenty-seven sonar scour monitors were installed at three bridges to provide a continuous ongoing record of streambed elevations. The monitors were designed and installed quickly, and were relatively inexpensive compared to other types of scour countermeasures.

In 1998, a pier failure at Wantagh Parkway over Goose Creek in Nassau County, New York, initiated the emergency investigation of the cause and the subsequent design repairs for the bridge (Figure 16). This was a 28.3m (93-foot) bascule bridge with concrete pile bent approach piers and 15 spans. The streambed at one pier was found to have had experienced approximately 8.8m (29 feet) of localized scour since it was built in 1929. The scour was not the result of a single storm event, but rather the erosion from various events over the years and the degradation caused by the daily tidal action at Goose Creek.

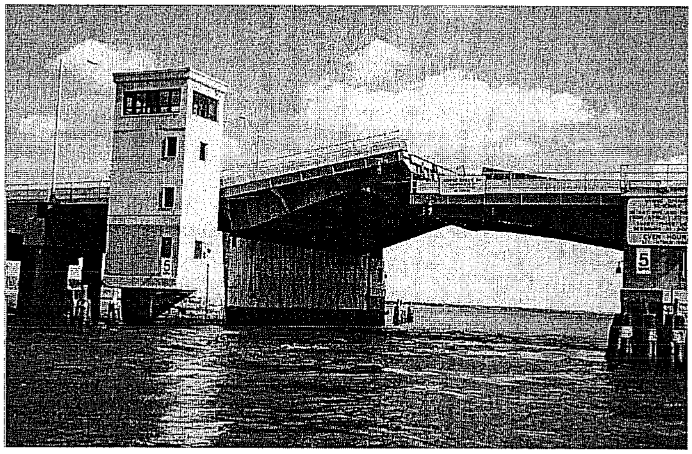


FIGURE 16 General elevation of the Wantagh Parkway over Goose Creek

This resulted in the downward movement of two piles and the fracturing of the pile cap above them. The outermost pile of this bent was left with only 0.37m (1.2 feet) of embedment in the sand (Figures 17 and 18). The owner, the New York State Department of Transportation (NYSDOT) decided to replace the bridge approach spans immediately, but the bascule piers would remain in service for about eight years. In order to ensure that these bascule piers were safe, several countermeasure options were investigated, and a scour monitoring system and program was designed for the bridge.

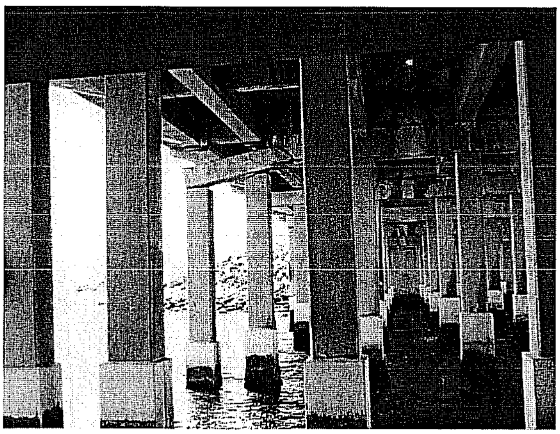


FIGURE 17 Failure of pier pile cap at Wantagh Parkway over Goose Creek

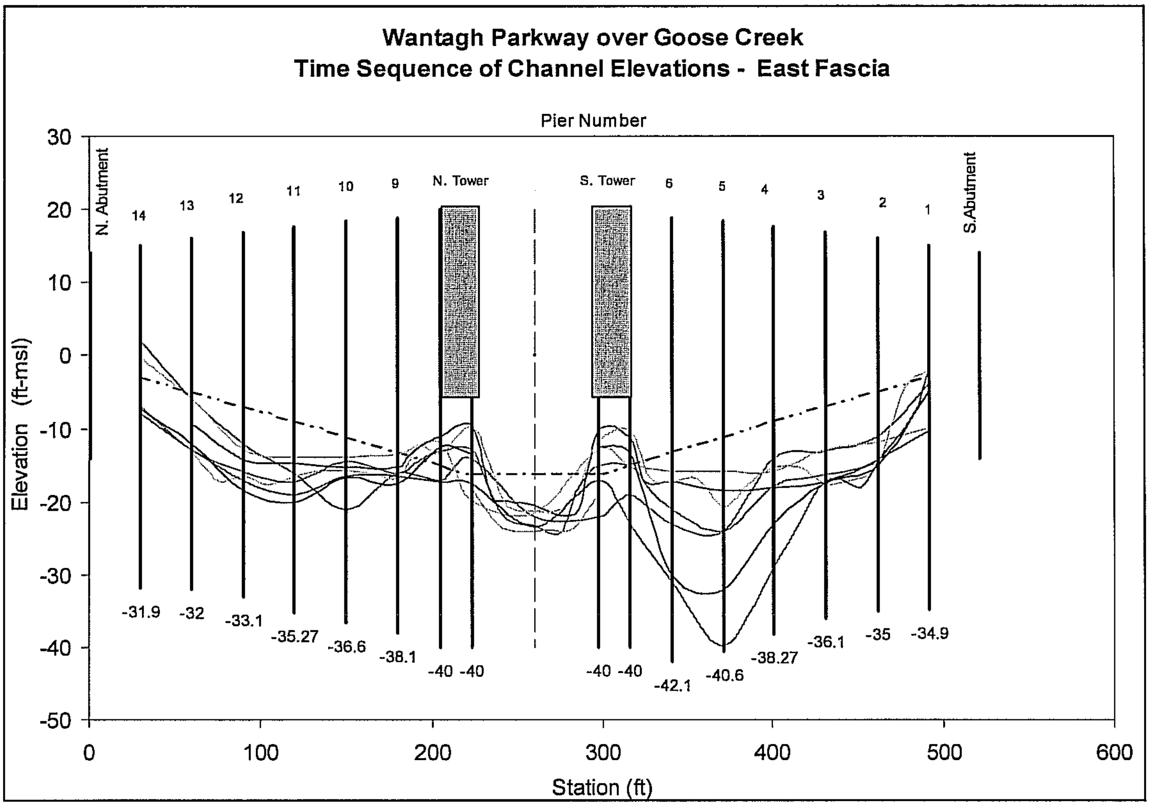


FIGURE 18 Plot of historic scour at Wantagh Parkway over Goose Creek

Due to the situation of the Wantagh Parkway over Goose Creek, a bridge just south of it, the Wantagh Parkway over Sloop Channel, was also examined. Built at the same time with similar pile depths, the Sloop Channel crossing had higher flow rates. This fixed concrete pile bent bridge was 175.6m (576 feet) long. It was found to have similar problems with respect to scour of the piers. As a result, four scour monitors were installed at the bascule piers of Goose Creek, and ten monitors were installed at Sloop Channel. In addition, a water stage sensor was installed at each bridge.

The sonar scour monitors were installed on either side of each bascule pier at Goose Creek. There were numerous piers with scour at Sloop Channel. A study of the historic diving inspections and fathometer surveys, the history of the riprap placement at the piers, the as-built pile tip elevations, and the most recent emergency diving inspection were used to determine which pier locations were most critical. The scour monitors, approved by NYSDOT within one week of the failure, were designed, custom-built, and delivered to the site ten weeks later (Figure 19). A temporary bridge was erected at Sloop Channel one year after the monitors were installed. The monitors were salvaged from Sloop Channel and placed in storage, serving as spare, repair parts for Goose Creek, or available to be used in rebuilding monitors for other bridges in the region should they require sonar scour monitors.

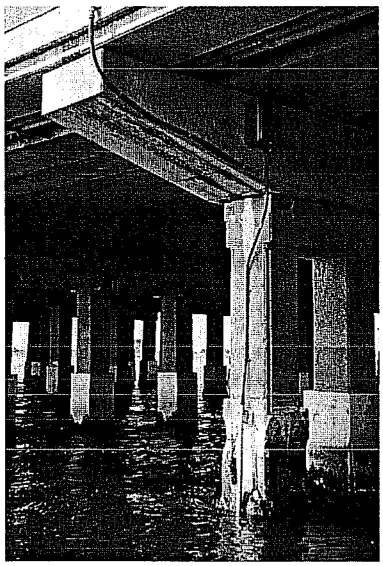


FIGURE 19 Scour monitoring system mounted to a pier on the Wantagh Parkway over Sloop Channel

A scour monitoring program and manual was developed for the two, Wantagh Parkway Bridges. This was the first procedural manual ever to be developed for scour monitors. The manual provided various options available for pursuit should these bridges continue to experience scour. Pier stability analyses were conducted for the bridges to determine scour cautionary and critical depths. The manual included cautionary and critical streambed elevations for each pier; procedures for normal and emergency situations; a plan of action should certain scour elevations be reached; and troubleshooting, maintenance, servicing and inspection instructions. An effective communication system for all responsible parties was established.

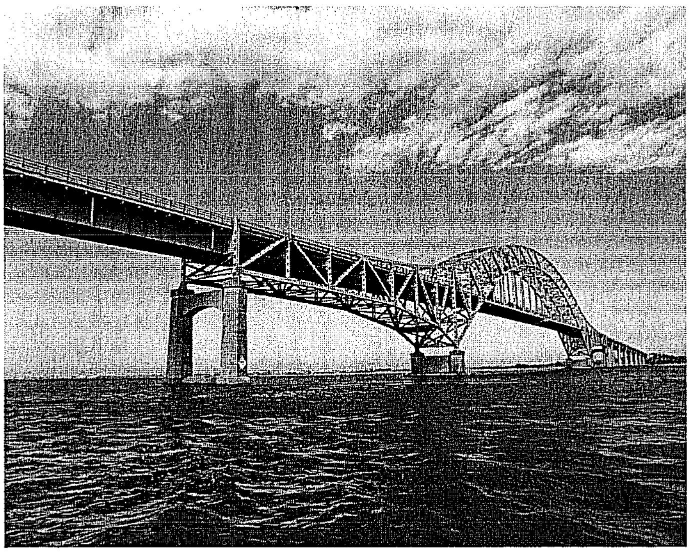
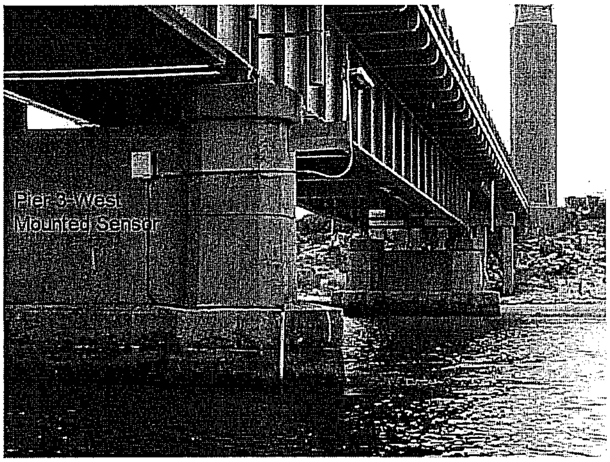


FIGURE 20 General elevation of Robert Moses Causeway over Fire Island Inlet

The 2001 installation of sonar scour monitors at Robert Moses Causeway over Fire Island Inlet in Suffolk County, New York, is a long-term solution to the scour problems at that bridge. The bridge is a 326m (1,068-foot), tied arch flanked by 24 approach spans for a total length of 1,290m (4,232 feet). Built in 1966, it has extremely high flow rates. For the 100-year storm, the flow rate is over 13,932cms (492,000cfs). Riprap scour protection had been placed at some piers over the years, and according to HEC-23 (3), riprap should be monitored when used as a countermeasure at piers. Sonar scour monitors were placed at 13 piers, a water stage was installed, and the Long Island scour monitoring manual was revised to include this system (see Appendix F). To establish critical depths, a pier stability analysis was conducted using the Florida Pier Analysis software for the piers that were considered to be the most likely candidates to experience potential scour failure. These piers were selected based on several factors including their location in the inlet, height, history of scour, and superstructure loadings. A scour analysis study was simultaneously conducted for a group of bridges on the South Shore of Long Island. The computed potential scour was used in the selection of the pier locations to be monitored. This was an extremely complex design and installation due to the proximity of the bridge to the Atlantic Ocean, the deep-water conditions, the pier configurations, and the high flow rates.

The scour monitoring systems at Goose Creek and Fire Island have been in operation for seven and four years, respectively. The scour monitoring program includes the daily routine monitoring of these bridges, including data acquisition and analysis; round-the-clock monitoring during scour critical events; the preparation of weekly graphs of the streambed elevations and tide gauge data; periodic data reduction analyses and graphs; and routine maintenance, inspection, and repairs. In 2004, a total refurbishment of the Goose Creek system was completed. This included the installation of the latest operating system software and a new bracket for the sonar transducer at one monitor location. An underwater contractor installed the new bracket and also strengthened the scour monitor mountings



at the other three pier locations. The condition of the scour monitors and the accuracy of their streambed elevation readings are checked during the regularly scheduled diving inspections at each bridge. Also, all debris and/or marine growth on the underwater components are cleared away during these inspections.

FIGURE 21 Detail of a sonar scour monitoring device mounted to a pier

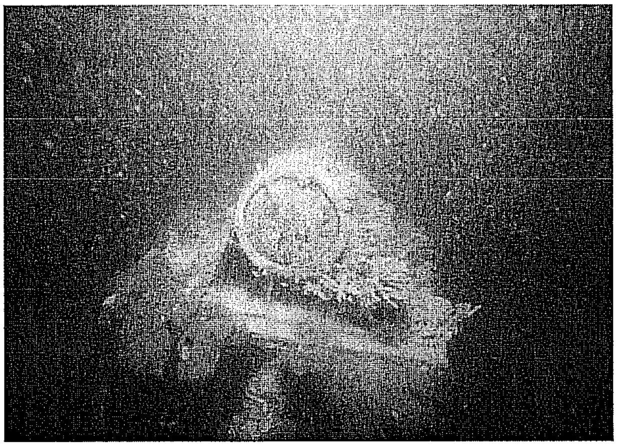


FIGURE 22 Marine growth on a sonar scour monitor

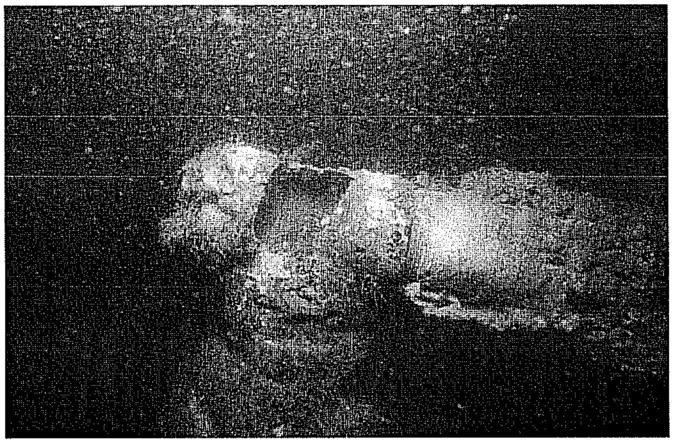


FIGURE 23 Damage due to corrosion and electrolysis

POTENTIAL SITES FOR FUTURE MONITORING

(Note to the Synthesis Panel: This section is still to be developed pending discussion of the survey results at the meeting, and direction as to what type of information they would like to get from potential sites)

Potential sites for future in-depth monitoring case studies were examined. These may include sites which have a large amount of information available, sites which have experienced, or are likely to experience scour depths, and sites where there may be funding to install scour monitors.

From the survey responses, extensive testing and analyses had been performed for the bridge sites in Maryland, Florida, Alabama and Long Island, New York. This information includes hydraulic computer modeling, hydraulic and scour analyses, borings, pier stability tests, and/or flume tests.

There are a number of new bridges in construction that may also be considered possible candidates for fixed scour monitoring systems.

The Maryland bridge is the new Woodrow Wilson Memorial Bridge over the Potomac River. The existing bridge has been monitored with sonar scour monitors since 1999. The Florida bridge,.Johns Pass, is also scheduled to be replaced. It was one of the test sites for the NCHRP scour monitoring project (1). The two Wantagh Parkway bridges in Long Island that were discussed in this chapter under case studies are going to be replaced. Extensive information is available for all these sites and the installation of a scour monitoring system during construction often reduces the cost and can provide a better, more secure installation.

Other sites that may be considered for instrumentation include the new bridge over Indian River Inlet Bridge in Delaware. Historically, this site has had extensive scour with as much as 30.5 m (100 ft) of scour in certain locations. The existing bridge has two piers in the channel, and they are protected by riprap. The new bridge will not have piers in the inlet, but a system could be designed to monitor the bulkhead. Also, there has been discussion that the inlet may be widened at a future date.

Other new bridges include crossings of the Mississippi and Missouri Rivers, and the new Tacoma Narrows Bridge in Tacoma, Washington.

Consideration should also be given to structural bridge health monitoring. These systems have many similarities to the fixed scour monitoring systems, including the data loggers. The possibility of integrating these two systems on a bridge may be beneficial, specially in terms of cost reduction and maintenance concerns.

SUGGESTIONS FOR A NATIONAL SCOUR DATABASE

Using existing databases found through the literature search and the data from the scour monitoring systems made available by the survey respondents, the following are suggestions on how a national database might be structured and what elements it might contain.

This includes information on assembling and maintaining this database. Databases that served as examples included the United States Geological Survey (USGS) National Bridge Scour, the Abutment Scour (South Carolina), and the National Water Information System (NWIS) databases.

DATABASE INFORMATION

A national scour monitoring database for the scour monitoring data could contain the following elements for each bridge site:

Bridge Information

- Name of Bridge
- Bridge Location
- Bridge Number
- Bridge Length
- Number of Spans
- Type of Bridge
- Average Daily Traffic (ADT)
- Year Built (and Rebuilt)
- NBIS Items 60 and 113 ratings

Scour Monitoring Information

- Type and Number of Scour Monitors Employed
- Installation Date of Scour Monitors
- Status – Active or Inactive and Why

Site Specific Information

- Waterway Characteristics
    - Waterway Type – Tidal/Riverine
    - Flow Habit
    - Water Depth
    - River Type – Braided, Meandering, Straight
    - Stream Size
    - Bend Radius
    - Bank Condition
    - Floodplain Width

    - Drainage Area
    - Slope in Vicinity
- Soil Conditions
- Extreme Conditions (Low/Medium/High)
    - Debris
    - Ice Flows
    - High Velocity Flows
- Functional Applications
    - Local Scour
    - Contraction Scour
    - Stream Instability

Narrative information would be added about the site, the scour history of the bridge and any emergency plan of action. Photographs would also be included.

Additional information could be included in this database, such as some of the other items in the national scour database. At the same time, the desire for a large amount of data needs to be balanced with the need to minimize the time required of respondents, and therefore increase the number of responses.

ASSEMBLING AND MAINTAINING THE DATABASE

The data could be assembled much like a search engine. For example, if a person is looking for sites with predominantly clay soils in debris-prone waterways, a list of similar sites could be readily generated for comparison. A main homepage could be set up where the user is allowed to choose specific bridge, waterway, and soil characteristics to narrow down their search. The search engine would list bridge sites that match the user's criteria in order of relevance. The user could then click on each bridge listing to view site-specific data. Links to sample data and graphs, agency information, manuals, plans of action, and scour monitoring vendor information could be listed as references for each bridge site. A contact name could be listed for each bridge for those who wanted to obtain more information about a particular site. This would also allow for an exchange of ideas and experiences between agencies.

Those responsible for maintaining the database would have to update the status, agency contact information, and available references for each bridge. This information could be updated once per year. The data could be collected one to two times per year. States submit their Bridge Scour Evaluation Program data to FHWA two times per year. Scour monitoring data could be requested and submitted at the same time. Some of the survey respondents indicated that they do not intend to keep the data for any period of time. Others said they plan to keep their data indefinitely. Those maintaining the database could collect this data annually or semi-annually as well. Reminders could be sent periodically via e-mail so that the respondents could reply and add an attachment with the scour monitoring data. Other measurements taken at the site such as water stage and velocity would also be collected for the database. If possible, all data could be converted into more user-friendly formats such as tables and graphs, and used as reference material for those searching the database.

CHAPTER NINE

IMPROVEMENTS AND FUTURE NEEDS FOR SCOUR MONITORING

This chapter discusses recommended improvements for, and needs of the equipment to be used at future sites. Scour monitoring solutions reported in the surveys and in the search for recent literature were discussed in Chapter 4. Suggestions that have been made regarding possible alternatives for improving scour monitoring technology are also included. Information on current guidelines, programs and manuals for scour monitoring systems is documented in Appendix F.

CURRENT STATE STUDIES ON SCOUR MONITORING INSTRUMENTATION

In addition to the NHCRP Project 21-03 on fixed scour instrumentation (1), several state DOTs have or are currently conducting research in this area. States that have conducted research in this area include Texas, New Jersey, Vermont, Oregon, New York, and Iowa.

The Arkansas State Highway and Transportation Department reported that they are currently conducting a project called "Scour Monitoring". Arkansas has identified approximately 100 bridge sites that require an FHWA plan of action due tot heir scour potential. They note that their current method of monitoring is ineffective because it is dependent on personnel visiting the site and taking measurements which may be before or after the maximum scour has occurred. Their objective is to recommend or develop scour monitoring systems that may be used to continuously monitor and record scour depths with a corresponding water surface elevations at a bridge site. These systems would automatically transmit this data to the proper authorities. The estimated project duration is one year and the work started in the fall of 2004.

The University of Hawaii, Honolulu is conducting a study for Hawaii DOT called "Instrumentation and Monitoring of Sand Plugging and Bridge Scour at Selected Streams in Hawaii". This project is installing, testing and evaluating data from scour monitoring and sand plugging instrumentation. This is being done to validate and modify existing scour equations so that they will be applicable to subcritical flow conditions at bridges in Hawaii's coastal zone; to begin the development of management and maintenance plans and engineering solutions to solve sand plugging problems along coastal bridges and culverts; and to investigate time-dependent scour development during flood and hurricane surges for bridges across tidal waterways in Hawaii by applying the real-time scour simulation model. This study started in 2000 and is expected to be completed in 2005.

Many of the owners who use or do not use fixed scour monitoring instrumentation stated in their surveys that debris is a problem with fixed monitors. The NCHRP Project 24-26 on the "Effects of Debris on Bridge-Pier Scour" started in 2004, and is expected to be completed by the end of 2007. The objective of this study of debris at bridge piers is to develop guidelines for predicting the size and geometry of the debris, and for quantifying the potential scour. The data from this study will provide information on debris that may be useful for analyzing a site, and for the design of the scour monitoring devices that can withstand potential debris forces.

LESSONS LEARNED FROM STATES THAT USE INSTRUMENTATION

A wide variety of responses were obtained when the bridge owners were asked about lessons learned from the use of fixed scour monitoring instrumentation.

The majority of states expressed maintenance concerns. Maintenance needs of the system were often greater than anticipated. One state noted that the devices take readings and report real-time data, but maintaining an operational system was very difficult. An on-going maintenance contract with a firm having special expertise with the scour monitoring equipment was recommended by another state. This contract should cover the entire period of the monitoring effort. The scour monitoring selection, design and installation is only a small part of the endeavor. Developing and maintaining a response protocol and responsibilities, as well as long-term functioning of the system, were the major challenges.

An additional concern was the is a need for stronger, custom-designed brackets. The materials used for the brackets should be carefully evaluated. The brackets should prevent movement, but be easy to remove to provide maintenance.

INFORMATION FROM STATES THAT HAVE NOT USED INSTRUMENTATION

The bridge owners who do not use scour monitors were asked to indicate what were the problems or limitations for why they had chosen not to use this technology. They were also asked to discuss innovations and advancements they would like to see in fixed monitoring technology.

The most common concern was the high cost of fixed monitors. This was followed by problems with reliability, and their desire for little or no maintenance requirements for the system. Other factors that owners described as contributing to problems with fixed scour monitors included: ice, debris, lightening, lack of funding, the long time required for installation, the poor quality of the data, and difficulties in the acquisition of the data. They also described various needs for their monitoring systems which included good reporting capabilities; remote access; negligible operating costs; systems that can withstand extremely high temperatures; that are protected from vandalism, particularly over ephemeral streams; that have the ability to take measurements through silty and murky water, and devices where all parts are outside of the water.

INNOVATIVE SOLUTIONS FOR SCOUR MONITORING SYSTEMS

It should be noted that solutions to some of the concerns expressed by bridge owners are already being implemented in the new monitoring installations, or are currently under development. Remote access for downloading scour data is currently being used successfully on numerous sites throughout the United States. One of the monitoring system vendors has designed and fabricated a movable sonar scour monitoring system for a bridge with debris problems in Alaska. This bridge had two fixed sonar scour monitors torn from it due to debris flows. This new system consists of a winch mounted below the bridge deck which lowers the sonar scour measuring device into the water at set intervals. When the sonar assembly reaches the water, it stops the winch, and the sonar can take a series of readings. The winch then raises the sonar back up, where it is stored and protected under the bridge deck.

An adjustable mounting bracket has been developed for use in underwater sonar monitoring installations where the geometry of the pier or abutment is uncertain. This enables those installing the monitor to adjust the bracket so that the sonar device clears the footing to take readings of the streambed below. Refer to Appendix D for a plan depicting this of bracket.

CHAPTER 10

FUTURE SCOUR RESEARCH NEEDS

SCOUR MONITORING INSTRUMENTS

The advancements that bridge owners would like to see for future fixed scour monitoring technology included the development of durable instrumentation, with increased reliability and longevity, decreased costs, and minimum or no maintenance. This equipment would include instrumentation that measures scour, and also water elevations and velocities.

The current fixed scour monitors will take a measurement in one location, and this point measurement may or may not be the deepest point. The deepest point of a scour hole may also change from one event to another. One state recommended the development of an instrument that measures the depth and location of the deepest point of a scour hole, or one that would map an entire scour hole. The multi-beam sonar technology that is currently being employed for fathometric surveys may be an option if this type of measurement is required.

SCOUR MONITORING PROTOCOL

As discussed in Chapter 4, the problems with maintenance of the scour monitoring system and program was a concern expressed by all the bridge owners with systems, and also by some who have not used them. The development of a detailed handbook on the implementation of a scour monitoring program is needed in order to help owners anticipate both the advantages and responsibilities of a successful scour monitoring system. The focus of the scour monitoring technology has been on the development and improvement of the devices. As described in the previous section, there are still many improvements that are needed for these instruments. FHWA is currently developing a new plan of action workshop and module. The project started in 2005 and is expected to be completed in 2006. It includes a section on monitoring instrumentation. This information should be useful in the development of a detailed, hands-on protocol for emergency actions for scour monitoring programs. An additional, more practical manual with guidance on how to ensure that the scour monitoring system remains active is needed for the DOTs and others that may be considering the use of fixed scour monitors.

(To the Synthesis Panel: The solutions and innovations that were noted in the surveys were few. Prior to the 2nd draft we would like to interview some of the respondents in an attempt to get more lessons learned information from them.)

INCENTIVES FOR OWNERS TO KEEP DATA

It was found that several bridge owners have already discarded data, or were not certain where the data could be found. This data is usually in text and/or spreadsheet files and could be easily e-mailed periodically to a designated data collection center. Bridge owners are asked to submit information on their Bridge Scour Evaluation Programs twice per year to FHWA. As discussed in Chapter 8, if a national database is created, the data could be submitted at the same time as the evaluation program information.

BRIDGES WITH TIDAL INFLUENCES

Although the NCHRP study on fixed monitors (1) tested only two tidal bridge sites, since that time, many bridges over tidal waterways have been instrumented with fixed scour monitors. The same devices that are employed in riverine bridges are being used on tidal bridges. Four of the thirteen sample sites that replied to the survey reported that their bridges with fixed monitors are over tidal waterways. In the case of bridges over tidal waterways, the worst scour may be on the ebb or the flood tide of the bridge. Scour monitors are installed on one or both sides, depending on where the scour has or is expected to occur.

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ACRONYMS

Abbreviations used without definition on TRB Publications:

AASHO	American Association of State Highway Officials
ASSHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
USDOT	Unites States Department of Transportation

GLOSSARY

BRISCO™ monitor
A fixed scour monitoring device. It consists of a sounding rod or falling rod attached to the bridge pier or abutment. As the streambed scours, the rod, with its foot resting on the streambed, will drop following the streambed and the system records the change in elevation.

Contraction scour
Contraction scour, in a natural channel or at a bridge crossing, involves the removal of material from the bed and banks across all or most of the channel width. This component of scour results from a contraction of the flow area at the bridge which causes an increase in velocity and shear stress on the bed at the bridge. The contraction can be caused by the bridge or from a natural narrowing of the stream channel. (1)

Fixed scour monitors
Monitors placed directly on a bridge structure. Recommended fixed monitors include magnetic sliding collars, sonar monitors, float out devices, and tilt and vibration sensors.

Float-out scour monitors
Buried at strategic points near the bridge, float outs are activated when scour occurs directly above the monitor. The monitor floats to the stream surface. An onboard transmitter is activated and transmits the float-out device's digital identification number to a datalogger.

Hydraulic Engineering Circulars (HEC)
Manuals published by the Federal Highway Administration offering guidance on stream stability and scour (HEC 18), evaluation of scour at bridges (HEC 20), and scour and stream stability countermeasure design (HEC 23).

Infilling
Re-deposition of loose, less dense soil into a scour hole

Local scour
Removal of material from around piers, abutments, spurs, and embankments caused by an acceleration of flow and resulting vortices induced by obstructions to the flow. (1)

Plan of Action	In the April, 27, 2001 memorandum, the Federal Highway Administration recommended that bridge owners develop a plan of action (POA) for each bridge identified as scour critical. A POA outlines specific instructions and measures that that should be taken to prevent the catastrophic failure of a bridge.
Portable scour monitors	Monitoring devices that can be manually carried, used at a bridge, and transported from one bridge to another
Pressure sensor	Measures the water elevation at a bridge
Scour	Erosion of streambed or bank material due to flowing water; often considered as being localized (see local scour, contraction scour, total scour). (1)
Scour countermeasures	A measure intended to prevent, delay or reduce the severity of hydraulic problems.
Scour critical	Coding as per the National Bridge Inspection Standards (Item 113), where observed or predicted scour would result in a loss of integrity to a bridge
Scour monitoring	Technology that includes fixed and portable instrumentation, as well as visual monitoring
Sliding collar monitors	Rods that are attached to the face of a pier or abutment. The rods have a collar that is placed on the streambed, and if the streambed erodes, the collar moves down into the scour hole.
Tilt sensors	Instrumentation which measures the rotation of a structural component of a bridge
Total scour	The sum of long-term degradation, general (contraction) scour, and local scour (1)
Vibration sensors	Measure bridge movement and the information is recorded by a datalogger